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Finite Element Analysis of Strain State Under Bending of REBCO Coated Conductors for High Field Magnets

Federica Pierro, Luisa Chiesa, Soren Prestemon[1] and Xiarong Wang[1]

Department of Mechanical Engineering, Tufts University [1]Lawerence Berkeley National Laboratory contact: Federica.Pierro@tufts.edu

Introduction

REBCO tapes are promising conductors for **high field magnet applications** due to their high current and high field capabilities.

During cable and magnet fabrication, REBCO tapes are bend around a former and **experience strain**. The brittle characteristic of the superconducting layer requires the **investigation** of the generated **strain distribution to avoid overstrain condition** and **damages** of the tapes.

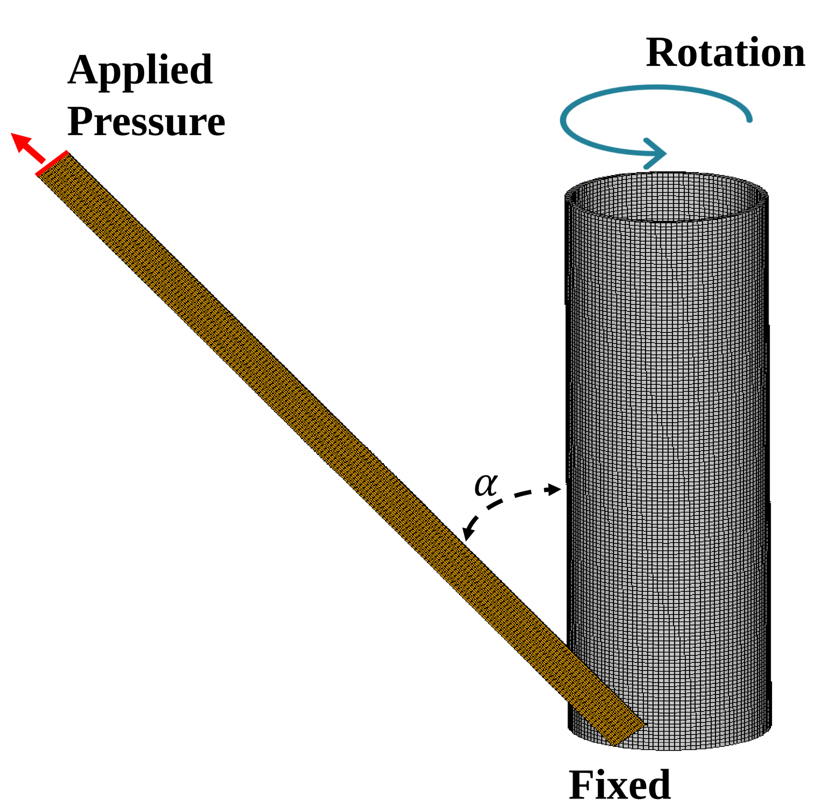
This work investigates the effect of bending on the strain distribution of a tape during circular helical winding, the typical configuration used for the conductor in round core cable (CORC®) [1,2].

Finite Element Analysis

Structural finite element analysis using ANSYS® was performed to investigate the strain distribution of a REBCO tape when wound in a helical configuration. 4 mm and 2 mm wide tapes were studied for different bending diameters and winding angles.
In each configuration, the tape was initially straight and in contact with a rigid cylindrical former. The tape was angled of α degrees; α being the winding angle between the base of the former and its central axis

Analysis Settings
- Tape modelled using SOLSH190 structural solid-shell elements
- Cylindrical former modelled using SOLID185 solid elements
- Surface to Surface contact pairs were prescribed between the former and the tape
- "Bonded" conditions were used in contact

Constrains
- Right end of the tape was fixed to the former
- Uniform pressure applied on the left end of the tape
- The former was rotated counterclockwise of 360º



Material Properties and Mesh

REBCO tape was modelled as a single homogeneous volume using bilinear material properties at room temperature. The cylindrical former was modelled as a rigid body, using material properties of stainless steel.
The mesh density was chosen to obtain accuracy of results while limiting the time of the computation.

Mesh Density
- 20 Elements across tape's width
- One element through tape's thickness
- Element size: 0.4 mm element size along tape's length and for the cylindrical former

Isotropic Bilinear Material Properties at 300 K [3],[4]

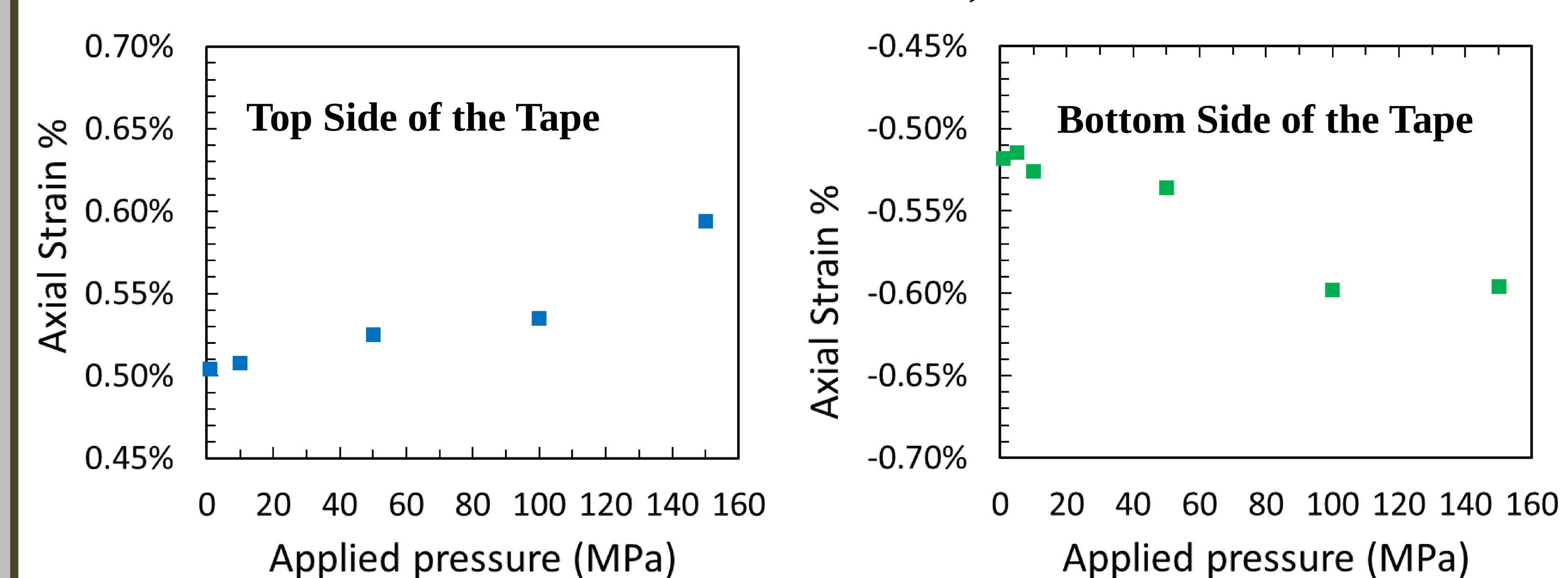
Material	E (GPa)	Y (MPa)	T (GPa)
REBCO (SuperPower)	145	640	8
Stainless Steel	180	950	10

Study on the Applied Pressure

Pressure was applied to the left end of the tape to maintained a constant tension during the winding. The applied pressure can affect the strain distribution within the tape and damages can occur. A study was conducted to identify the optimal pressure to allow winding for different former diameters and winding angles while minimizing the overstrain due to the extra tension on the tape.

- Increasing pressure, increases the maximum strain experienced by the tape.
- At 150 MPa the strain is 17% higher than the strain at 1 MPa
- **10 MPa** was identified as the optimal pressure does not significantly effect strain distribution of the tape (1% higher than 1MPa) while maintaining a good level of tension.

Former diameter 20 mm, α 60º



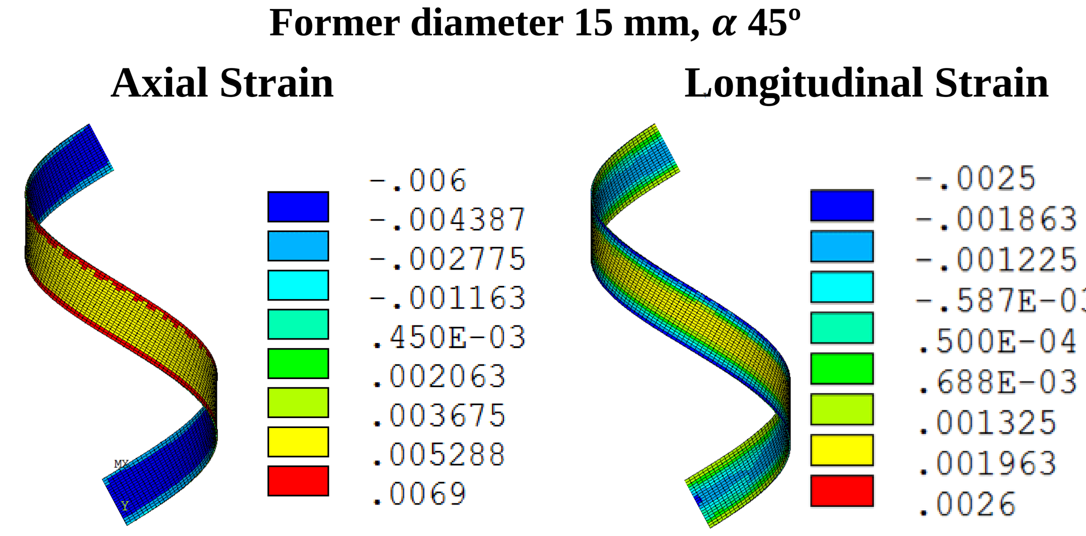
Finite Element Results

- **4 mm wide REBCO Tape**

Axial and longitudinal strain distribution within a tape were investigated for different former diameters and winding angles using a 4 mm and a 2 mm wide REBCO tape.

Former configurations studied:
- Diameter 20 mm, α 60º
- Diameter 20 mm, α 45º
- Diameter 15 mm, α 60º
- Diameter 15 mm, α 45º
- Diameter 10 mm, α 45º

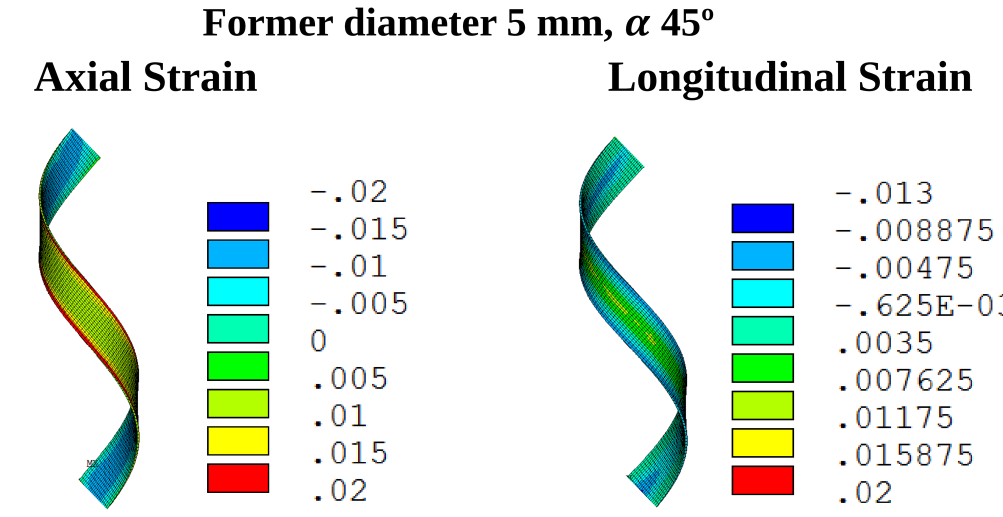
Former diameter 15 mm, α 45º



- **2 mm wide REBCO Tape**

Former configurations studied:
- Diameter 7.5 mm, α 60º
- Diameter 5 mm, α 60º
- Diameter 5 mm, α 45º

Former diameter 5 mm, α 45º



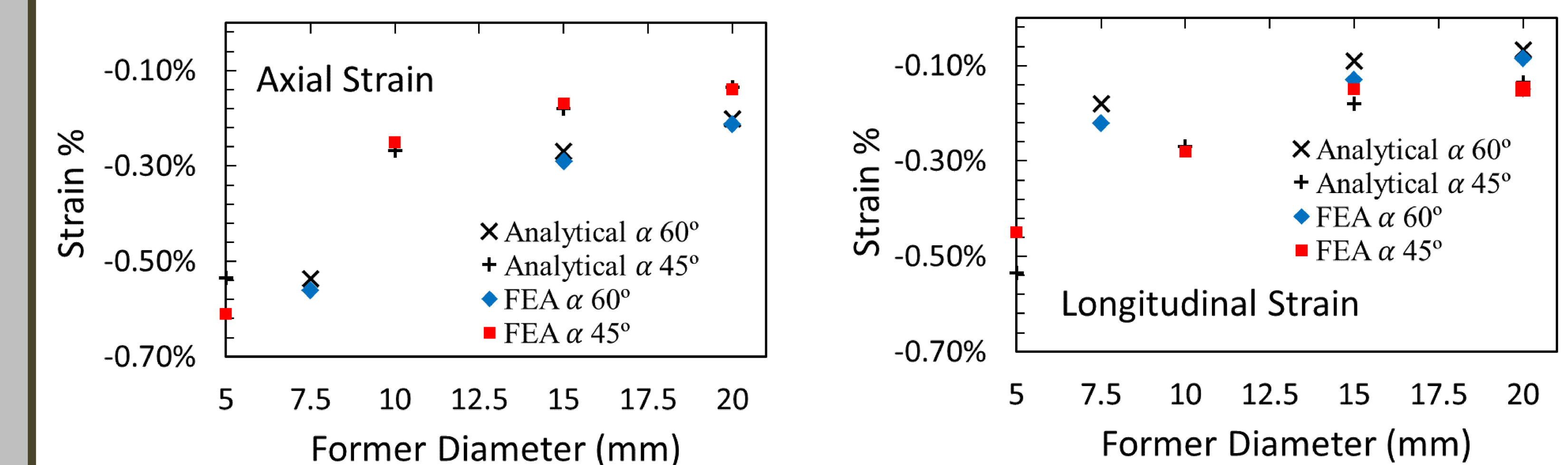
- For both the 4 mm and the 2 mm wide tape the strain is uniform along the tape axis but changes across the tape width due to Poisson's effect.
- The strain distribution on the bottom side of the tape is influenced by the bonded contact assumption made in the model.

Strain on the REBCO layer

- Because the REBCO layer does not lie on the neutral axis, it experiences strain during winding. If the winding is done with the substrate side facing upward, the REBCO layer is expected to be in compression. Strain distribution at the superconducting layer location can be found by interpolating the strain results for the top and bottom of the tape.
- Results were obtained half way along the tape's length to avoid ends effect. Maximum values across the tape width are reported. Results are compared with the analytical solution obtained by:

$$\in_{axial} = \frac{d \sin^2\alpha}{r}, \quad \in_{longitidinal} = \frac{d \cos^2\alpha}{r}$$

d: distance from the neutral axis, r: bending radius



- Good agreement found between finite element and the analytical results
- Smaller bending radius results in higher axial and longitudinal strain
- Smaller angles cause higher axial strain distribution in the tape

Conclusion and Future Work

The strain distribution obtained with finite element analysis provides useful information to predict the critical current degradation of the tape during cable fabrication.
Future work will focus on predicting the critical current degradation based on the FEA results. These results will be validated measuring the critical current at 77 K in self field.
3D printed formers with different diameters and winding angles have been fabricated and measurements will be completed in the next six months.

Additional bending configurations relevant to high-field magnet applications will be analyzed, including canted-cosθ (CCT) dipole single tape and cable.

References

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